Towards Production Network (PN) Theory: Contributions from Systems of Models, Concurrent Enterprising and Distributed Manufacturing

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Abstract- **Production Networks (PN) fundamentally differ from hierarchical organisations, as they emphasise on speed, re-linking, and reconfiguration. For the decisions for realignment of units and the reallocations of resources, configurations on changing levels of detail and control actions, generic models in line with concurrency modes give an adequate base for the description, the control and the evolution of PNs. Simultaneous application of selected interrelated models may generate very efficient procedures for PN management. Moreover, collaboration between dispersed locations is well ICT supported. However, for lack of overall conjectures, management solutions are fragmented. PNs may generally be modelled as Hausdorff spaces and the respective tangent spaces. Specific mappings as well as applications of concurrency modes may be introduced for improving coherence and speeding up decisions. Methods and models appear as embedded structures, carrying the fold/unfold properties of graphs and systems. Interoperability requirements induce standardizations for the models. The specific synthesis of the concurrency modes with criticality thinking results in procedures for gradual and evolving adaptations of production networks' structures, most adequate to PN' complexity. Ground laying theory always strengthens the convergence of terminology, methods and models that are developed and applied on a research area. In this sense, this paper intends to contribute to a coherent body of knowledge for PN design and management by theory building.**

Keywords*- *Concurrency Modes; Generic Models; Network Evolution; Collaborative Planning; Cyclic Decision Procedure; Criticality

I. INTRODUCTION

Production Networks (PNs) are complex, and the concepts, typologies and software supports have generated so far mostly isolated problem solutions. Incoherent approaches, originating from these different problem aspects have only led to heterogeneous and non-consistent model fragments. PNs, often interpreted as Supply Network configurations, are also to be envisioned as results of dynamic capabilities, Virtual and Extended Enterprise approaches and Grid Manufacturing. There are considerable impacts of complexity in organizational applications. In the information technology fields, solutions are seen in object-oriented modelling and techniques for performing enterprise modelling. For globally distributed and coordinated supply networks holistic views, enterprise architectures (EA) and modelling approaches have been provided. These methodologies include e.g. I-CAM and CIM-OSA with subsequent standardization. Also well-known and solution-oriented are ARIS, SCOR, PERA, GERAM, VERAM, GRAI-GIM or First STEP, considerably contributing to progresses in descriptions and norms. However, these frameworks neither intend to explain network phenomena nor help to operate PNs. In order to use the power of ICT for PNs more efficiently, specific solutions focusing on information transparency have been proposed with Covisint, Everest, ICON, LiNET, STEP,PL, XML and the (ML) open COLLADA standard. The results must remain unsatisfying since close firm interrelationships have to be the starting point of ICT efforts and cannot be assumed as outcomes thereof. As solution for interface problems and to enhance the responsiveness of supply networks, Supply Chain Cooperation (SCC) is postulated. Still, the ICT focus stays clearly preponderant. This is clearly underpinned with concepts like Built-to-order supply chain (BOSC), Efficient Customer Response (ECR), Continuous Replenishment Planning (CRP), VMI or FGP, simply aiming at smoother flows in PNs, mainly by transferring responsibilities to the suppliers, obliging them to hold high stock levels. Multiple forecasts within the supply networks, changing demand patterns and general synchronization problems call for Collaborative Planning, Forecasting and Replenishment (CPFR). However these approaches too fall short, even if accompanied by firm alignments via standards as proposed by the Voluntary Inter-industry Commerce Standard Association (VICS), as they all fail to scale adequately and the operation can be very laborious, as they ignore fundamental problems of collaborations involving diverse self interested actors with a variety of barriers and conflicting motivations [6].

Control design using agents on the process level is a field of comprehensive research work. Starting with the spreading application of agent systems within Internet technologies, the agent systems also have been applied to PN control. Agents are basic building blocks of Complex Adaptive Systems (CAS). Multi Agent Systems (MAS) have been developed for the application within various fields. The aim of the Holonic and PABADIS architectures is the integration of the benefits of the above mentioned architectures. Results are most flexible and overall applicable control architecture useable in all field of distributed control. The most important works in the Holonic field is the PROSA and for the PABADIS field the PABADIS architecture with the subsequent Automation ML standard [4] that will be referred to below.

Resulting from these multiple approaches, large portions of the acquired knowledge about PN are cast into rather singular models or solution procedures uniquely based on case experiences and anecdotal verifications that need to be further validated. Network principles in manufacturing replace

hierarchical management and give competitive advantages, as the "certainties" of command and control approaches evidently seem to no longer "hold true". A company may see itself primarily as unit in a network, getting value out of this loosely coupled enterprise [11] by focussing on distinct process segments and by excellence in attracting a maximum of network resources towards its visions and objectives. Analysing operations networks through the lens of Complex Adaptive Systems is advantageous [15] for the fact that contemporary operations setups rather resemble dynamic, complex, interdependent, and globally distributed webs, than the static well determined systems, which have traditionally dominated our thinking. Within simple settings of collocated operations, the challenge of managing can still be achieved by conventional planning systems and other intra-organisational decision mechanisms. For networks, management becomes much more complicated, as the involved units and their roles are not stable, but evolve dynamically. However precisely these properties are, activated for incorporating changing external partners as well as varying capabilities and knowledge, enormously increase the companies' adaptabilities [14] and strongly amplify differentiations and uniqueness. This means continuous restructurings and adaptations for manufacturing networks. For the decisions on structuring, re-linking, or breaking up connections in manufacturing networks, generic models and modes are introduced to support adequate interventions. The outline attempts to generalise solutions that have been successfully implemented for distributed manufacturing [7], which is based on self similarity and other concurrency modes. It intends to contribute to specific production network sciences.

II. PLANNING AND MODELLING IN DISTRIBUTED STRUCTURES

Planning and control in PNs do not regard the units themselves. Various models and attributes of these units are manipulated and put into relations. Each PN planning step makes use of a number of such models raising the question of how the dependencies and simultaneous planning actions influence choices, attributes and levels of detail of the models involved. Therefore the network units' interaction structure must be envisioned as an interrelations' structure of the models. As an example for this principle, the arrangement of equipment within a factory layout may be given.

A. *Interrelated Models for Planning*

It is generally assumed that the site of a unit in the layout plan depends on the material flow, the process sequences, the overall layout, and technological influences. Traditionally it is outlined that any conception of production systems is to be executed by top-down-procedures, assuming proportional relations between length of planning horizon and planning object detail. Inevitably the construct will supply corresponding views of planning horizon lengths and details of planning object levels. Long range decisions are envisioned in direct link with rough sketches and low precision, whereas short planning horizons are associated to details in alternatives and variants for processes and factory layouts. It is well known and widely tolerated that the resulting "one time" solutions are sub optimal, not able to cope with volatile market demands. Variety and unpredictability call for versatile productions. Models contributing to decisions can be put into a planning impact diagram, and are activated for decision making (Fig. 1).

Production re-configurability requirements evidently turn hierarchical planning into a concurrent planning process engaging interrelated models, attached to the network units. Moreover, variety and unpredictability require close collaborations in networks.

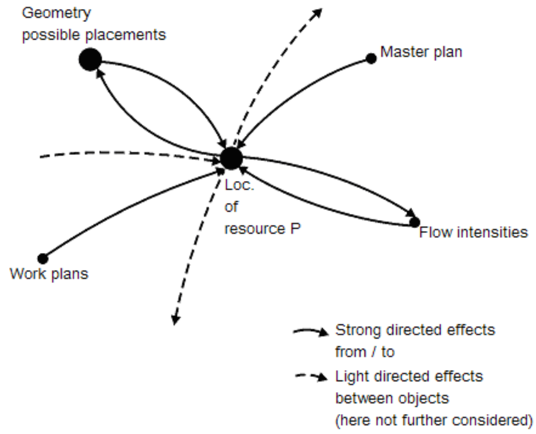

Fig. 1 Planning impact diagram: impacts and relations between units' attributes for a planning issue with determination of optimum location of machine P in layout plan

There is permanent need for planning, using all model attributes required concurrently and in distributed structures. Online Collaborative Workspaces with wide access to conceptual modelling, mind mapping, CSCW, mind mapping etc. offer immersive inter-personal communication structures to cope with these challenges. Such concurrent procedures assume a "supply of models", which is permanently available and may be instantly activated at the requested attribute and detail level. Models of the mentioned unit attributes as flows and restrictions and geometrical attributes contribute to decisions of resource allocation and could be put into a planning impact diagram, and are activated for collaborative decision-making (Fig. 2). The decision on an optimum machine layout within a multi-site PN can be done in an interactive collaborative planning step.

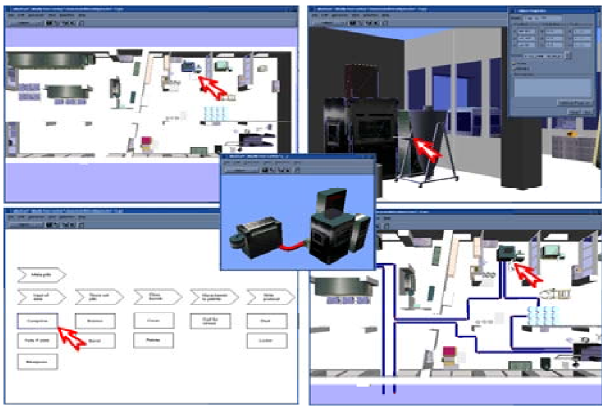

Fig. 2 Concurrent planning by virtual reality: collaborative workspace example for process optimization

Parallel proceeding in planning processes assumes updated and precise information about dependencies of attributes and planning objects and the assigned models respectively. Relations and dependencies are of network nature (e.g.) and may be mapped by impact arrows. Intensities of impacts may be formalized in matrices (cross-impact matrices). These impact relations may serve as decision support for the choice of model sets as well as the switch of view used in the respective collaborative planning step. Therefore the procedure assumes model systems that can be used for special problem solving,

questions and planning situations. For the machine layout, the adequate models to be chosen are flow charts, Sankey graphs, DMU/VR and geometry of plants and machines. A number of models are to be prepared to start with; later the model system will evolve with every planning session. Possibilities are offered to generate numerous alternatives and variants that would not have been possibly detailed in sequential planning. The main advantage is the option to represent all constellations distributed and graphically connected with the planning step. Additional options are offered, i.e. planning in interdisciplinary teams by moving ("navigating") through the model system on demand, based on prepared models and data. These excellent technical solutions, primarily set up for production systems planning should and could be extended for PN applications.

B. Collaborative Working Environments (CWE)

Other ICT approaches tackle collaboration in network issues, as within PN structures. People will no longer work individually but rather as dynamically assembled groups of diverse and complementarily skilled professionals working together within shared collaborative working environments (CWE). Working patterns become extremely complex due to the wide range of collaborative activities and the large numbers of dispersed and changing units, and also due to the virtualizations of the workplaces [13]. As business becomes more global and broadband and connections are increasingly becoming available, PNs should be benefiting better from its multiple advantages. However, a number of novel factors are affecting collaboration effectiveness and efficiency. These factors are creating novel types of distances. A table of CWE tools and technologies contributing to overcome collaboration barriers from the viewpoints of a representative number of individuals is presented below (see Table Ⅰ).

TABLE I FRAMEWORK FOR TOOLS AND TECHNOLOGIES CONTRIBUTING TO TAKING INTO ACCOUNT OF DISTANCE FACTORS

Dimensions	Distance Factors (due to the lack of)	WebConf	IM	Whiteboard	SW	Forum	Blogging	Wiki	eMailing	VR & AR	MWC	Polling	Semantic	Modelling	Workflow	SN	SG	EA	EN
Structural	Collocation (shared-space)			X	X			X		X									
	Communication	X	X			X	X		X										
	Coordination														X			X	X
	Leadership											X					X		
	Incentive															X	X	X	X
	Cohesiveness																X	X	
	Shared vision											X		X			X		
	Interoperability												X	X					
	Balanced decision	X										X					X		
	Synch. interactions	X	X	X															
	Asynch. interactions				X	X	X	X											
Social	Shared culture					X	X	X						X		X	X		
	Mutual understanding			X						X			X	X		X	X		
	Trusted relationships						X									X	X		
	Context awareness									X	X							X	X
	Social translucence																	X	X
	Interpersonal relationships						X									X	X		
	Social interactions	X		X		X	X									X	X		
	Emotional awareness	X	X				X			X						X	X		
Technical	Absorptive capacity		X							X							X		
	Shared references							X								X			
	Technology skill									X							X		
	Shared meanings			X									X	X					
	Shared relevance													X		X			X
	Correlation												X						X
Legal	Common IPR							X											
	Common Privacy Rules				X														
	Common Security Rules				X														

This framework (Table Ⅰ) helps to disentangle distance factors in PN collaboration by using interrelated models either. It consolidates results of empirical studies, as well as better understanding the implication of distance. New ICT options might be even creating more distance or reversely helping to bridge or compress distance, by having a positive impact on distributed collaboration performance. Although there are progresses, planning in distributed structures and developments as CWE are separate fields that should be put onto a common base.

III. GENERIC MODELS

One of the keys is certainly a change in network management. Networks are obviously controlled or attracted by directives and objectives. Re-configurable dynamic set ups are interrelated, inter-linking/detaching units, establishing and optimizing varying and changing process chains. Global order structures may "emerge" as a result of local interactions if networks will self-organize towards attractors. Business opportunities may represent "attractors" that orientate and reconfigure production networks. Therefore we may understand a PN as consisting of self-organizing, self-interested units with own processes and structures moving within network configurations on different levels of detail. It appears that a few configurations are more favourable than others in some way and applicable models should show fold/unfold properties.

A. Spaces of Activity and Criticality for Decisions and Control

As a common representation of the nodes, the Spaces of Activity may be described by the units' objectives, the resources and constraints. In consequence, the SoA volume may be identified by the unit's decision space, i.e. admitted zone, for the units' positions. The unit's SoA position, e.g. expressed by corresponding indicators, gives input for decisions on maintaining the unit's self-organization mode or reducing autonomy and calling for external interference. In cases of a unit's inability to cope with the objectives or the changes in the environment, network "order parameters" may gain influence on the units' activities of (self) reproduction, (self) destruction, and (self) structuring.

For the decision, if harder efforts or even adaptations of the network are needed, we may envision the Spaces of Activity as criticality thresholds [5]. In situations of overriding, this "interaction flag", i.e. an observable moves into an invalid position (Fig. 3), the units' criticality exceeds the assigned threshold and immediate actions are initiated. Usually there is more than one way to interpret a particular critical situation, so the solution options may range from "the status may just be adjusted or adapted" up to "the situation initiates severe interactions". If any units repeatedly fail to supply the promised/necessary capabilities, these units become "critical units", e. g. units that are roles within the network must be checked. In the repeated cases of criticality, the question is to be raised, whether keeping a unit in the network that is unable to avoid criticalities isn't a waste of potential and resources.

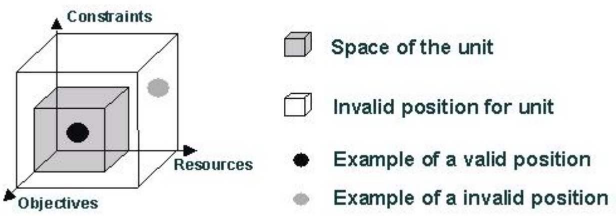

Fig. 3 Units' space of activity (SoA): viewing (valid or invalid) positions of relevant indicators and observable

For adequate differentiations of criticalities, a comparison integer for characterising the repeated "not admitted" situations may be introduced indicating the least number of comparisons

that may be accepted in a particular decision situation: the higher the number of "not admitted" situations, the more critical that unit becomes. If the number of comparisons resulting in "not admitted positions" is higher than the accepted integer, the unit will run into a "more severe" decision cycle. Applied for manufacturing network decisions, such "criticality thinking" will result in a levelled manufacturing network adaptation procedure, similar to findings in complex adaptive systems [3].

IV. INTERRELATED CRITICALITY THRESHOLDS AS A BASE FOR DECISIONS

Good network units' decisions will evolve the networks in economising resources, fulfilling objectives and strengthening/enabling the networks in total. Most promising for planning and decision in manufacturing networks seem to be approaches, engaging distributed and concurrent procedures that continuously and progressively generate "evolutive" solutions [1]. All processes appear as embedded in rich structures of actors, units and connections, which may arbitrarily be compressed/detailed by fold/unfold properties (Fig. 4) applying self similarity properties [6]. Any critical state on a lower level may have an impact on the criticality of the involved unit as well as on units of more aggregated network levels or even the configuration of the total network.

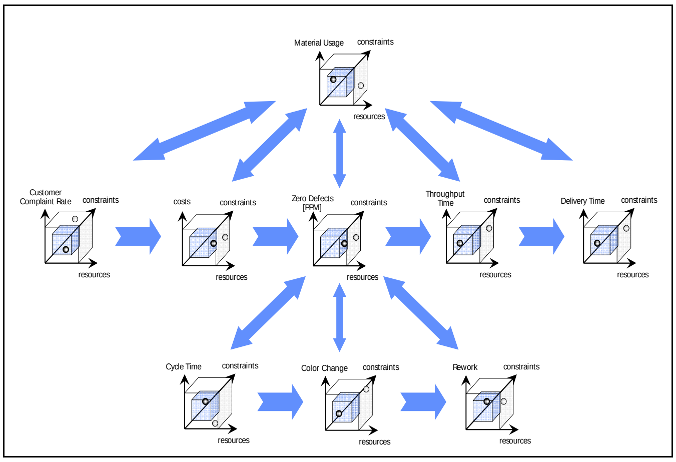

Fig. 4 Self-similar breakdown of SoAs and criticality thresholds onto levels of detail

Arising criticalities are to be negotiated and harmonized with other units' objectives and resources. In extreme cases, the total networks' objectives have to be refocused in order to eventually obtain a consistent set of criticality thresholds.

If the number of comparisons resulting in "not admitted positions" is higher than the assigned integer, it will run into a "more severe" decision cycle. Eventually the unit's SoA positions result in decisions on maintaining the self-organization mode, reducing or removing the autonomy, and calling for PN interference. In criticality terms, each unit may decide on appropriate methods, tools, etc. in order to achieve the objectives being negotiated and agreed upon. Units remaining within the admitted SoA are allowed to execute autonomous decisions.

Prerequisites are resources, e.g. budgets, competencies, technical and personnel availability, and constraints (a unit may have to face legal restrictions and capacity limits). If non-critical positions within the unit's SoA are not achieved by their own efforts, the autonomy will be loose. Instantly network mechanisms are activated preventing the deviations and providing for the network plan's achievement. Being replaced by new or other network units and being removed from the network if II) is repeatedly experienced.

Dependant on the unit's ability to cope with changes in the environment, network order parameters may gain influence on the units' activities according to the subsequent scheme:

a) admitted position: no action

b) sporadically no admitted position: non critical, self organised optimisation when the unit is demanded

c) repeatedly no admitted position (within threshold): (critical) autonomous self organisation, where the critical state is overcome by the respective unit;

d) repeatedly no admitted position (exceeding threshold): (critical) interaction, where the network asks for changes in criticality values (Space of activity Volume, while presenting expected benefits/drawbacks that account for the critical situation; and

e) repeatedly no admitted position (exceeding threshold by far): (critical) restructuring, where alternative structures (breaking up of links, generation of new interconnections, and introduction of new entities) are checked and the results are compared.

The ability to do quick, precise, and reliable parameter settings and monitoring, concerning the objectives as well as the resources' states, is essential for efficient network management. Necessary improvements, reconfigurations, realignments or restructuring actions as well as adaptations should be possible without any delay or reaction times. The proposed criticality framework offers these options and makes the management of manufacturing networks easier and more structured. Plans, assignments, units, responsibilities etc. may continuously be rearranged, processes (re)established or (re)configured, if necessary by making use of additional units or by eliminating certain units or collaborations. In addition, after execution, the framework defines a network request, i.e. an explanation (global explanation) for the choices made during the decision. For economic reasons the network will try to keep the volumes of the Spaces of Activities somehow limited. The Production Network may react on any increase of market complexity (diversity, uncertainty and unpredictability) by expansion of the SoAs affected (if affordable). More foreseeable steady conditions allow shrinking the SoAs' volumes.

On the layer of manufacturing execution control constituted by Order Agent, the Ability Broker, Resource Agent, and the Product Data Repository criticality are expressed by the ability to provide and/or use manufacturing capabilities or the data relevant to them [9]. Hence, thresholds are based on minimal capability provision. The threshold monitoring of the involved entities will focus on registered capabilities and manufacturing processes where the improvement and adaptation processes have top focus on the registered manufacturing capability portfolio. On the layer of enterprise resource planning, criticality is expressed by capacities, available for the execution of the required manufacturing processes. Therefore, the involved criticality thresholds follow minimal capacity scenarios.

However, the procedures totally executed by the agents are not powerful enough for Decision Support on production networks' level. Adequate extensions will have to support the

network in achieving all vital objectives, monitoring and analysing factors and indicators, especially focusing on those putting the objectives' achievements in question (Fig. 5).

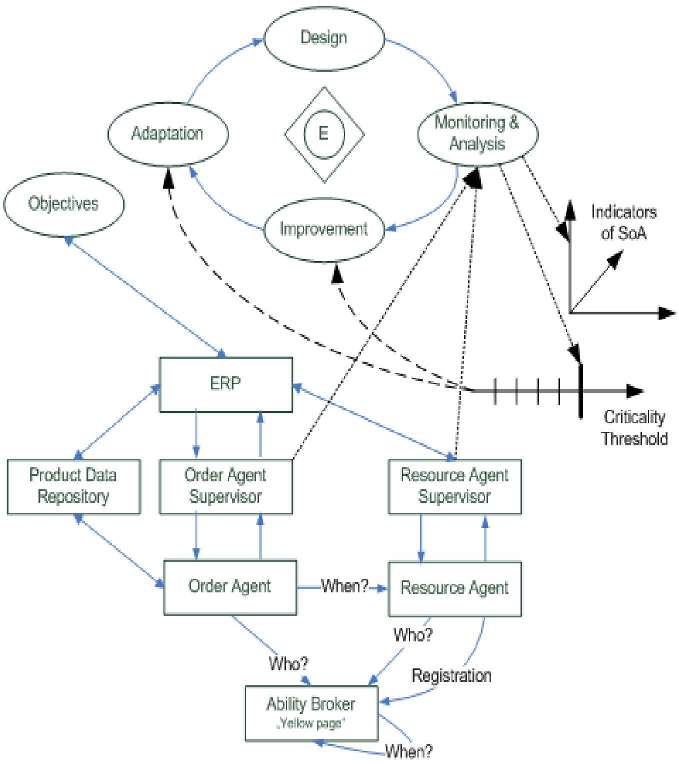

Fig. 5 Decentralised control architecture: PABADIS PROMISE in MES, a specific implementation of the criticality concept

For decentralised decision-making based on network business model special logics, algorithms and methods for integration and management seem to be necessary. Both objectives and resources appear "dispersed". This concerns the matching of partners as well as the temporary collocation of operations in production networks; all units as well as all interrelations have to be monitored. Extending the criticality based procedure as described above to the network management level may include the attempt to automatically generate suitable manufacturing processes and units' candidate lists. Therefore, extensions require major modifications of the models used, as the procedures have to prepare complex decisions and cannot be completely left to multi-agent software logics.

All network resources are embedded in a strategy and the resulting objectives for the manufacturing network. Units or even subunits criticalities' may have an impact on all enterprise units involved. Both objectives and resources may be assigned "dispersed" and self-similarly modelled as well, introducing levels of details. On the basis of this generic model, logic for the meshed control of (partial) autonomous units for configurations decisions, containing systems and networks in networked manufacturing structures, may be established.

A. Strategy and Objectives:

Clear visions and missions and well defined strategic paths establish the parameters for the network design bringing about major and disruptive changes, potentially including excellent new opportunities. The network gets vision, mission, and network draft, later detailed design to operation. The network strategy has to support the idea that, in order to truly align the infrastructure with business requirements, units must be free to choose the solutions that best meet their unique needs and based upon open standards.

B. Network Design

The network is to be configured to meet customer requirements best. Partners, units and other actors are identified and linked to a network structure. Procedures as GERAM are available for support. Processes have to be linked and assigned to responsibilities. Objectives have to be broken down and resources to be budgeted. Actors, units and partners are identified to embed the processes as needed. The strategy elements may be broken down to the decisive factors and the respective indicators that cover all key areas for the networks' businesses. Objectives may be decomposed and the decomposition logic should be adapted to the structure of the units to be configured. They may result in vertical relations of sub objectives and/or aggregated objectives' systems.

C. Monitoring and Analysis

This phase describes the activities that constantly update the units' potentials, capabilities or availabilities or that check the network for underperforming units and that notify the network in cases of outages or other alarms, recognised by units' criticalities. Structures, mechanisms and outputs are studied, compared and rated. These analyses may be driven down to sub or sub-sub levels where resource configurations and their contributions to the objectives as well as the SoAs structures (incl. the criticality settings) are broken down applying the self- similarity principle.

Necessary actions, dependant on the monitoring and analysis results as well as on the criticality of indicators and units, are executed as subsequently outlined:

1) Improvement:

In cases of less severe criticalities, simple structural-functional or parametric adjustments or objectives' alignments are initiated. Improvements within a manufacturing network can be achieved through changes within the network units themselves, most of these can be pursued independently of network considerations. Important steps may be the introduction and enforcement of methods supporting improving actions. Modified objective settings may lower or remove criticalities and enforce the entities' contributions to the network. In consequence, distinct criticality thresholds may be varied, which again puts pressure on the improving actions.

2) Adaptation:

Severe criticalities will provoke networks' reconfigurations. These interventions have to be considered as the most powerful reactions of networks in order to catch up with networks objectives' deviations or underperformances. These may be necessary when feedback processes that once were able to adjust or influence the improvement behaviour of the network can no longer produce the desired outcome. When efforts to improve performance and market position continuously fail, managers of organisations will resort to major interventions in an effort to produce radical change. New patterns of behaviour and different structures may need to emerge, and these may become established through new positive feedback from units.

3) Decision:

The Decision phase marks the point where the necessary initiatives are taken in order to support the networks evolution into the intended direction. Initially objectives may be sub-structured according to the granularity of the units referring to.

For production networks, the interrelations of objectives, processes and network structures are predominant. Network units are changing constellations, to be inserted, removed, shifted or melt. In networks, the focus is being executable and straightened out for objectives to be useful for the network units' leadership. In this sense the network is constituted of linked "smallest" processes and the network units are defined as a main process on base of transformations, where the interrelations of unit, sets of objectives and efficient and effective order processing are crucial issues.

All decisions of importance may be taken, revised, improved or repeatedly cancelled within this cyclic procedure (Fig. 6) i.e. previous program strategy, network configuration, make/buy decision, site decision, process/technology/equipment decisions, etc. are revisited regularly. History and time (complexity attributes) might hinder to execute the resulting decisions immediately. Structures might exist that cannot be instantly eliminated or the building of new competencies will take some time. For the modelling of the network it is therefore recommended to maintain other models beside the model of the given actual network. These models should provide "what if" evaluations and simulated comparisons of indicators that are visible, to what extend the actual situation "suboptimal" influences the network.

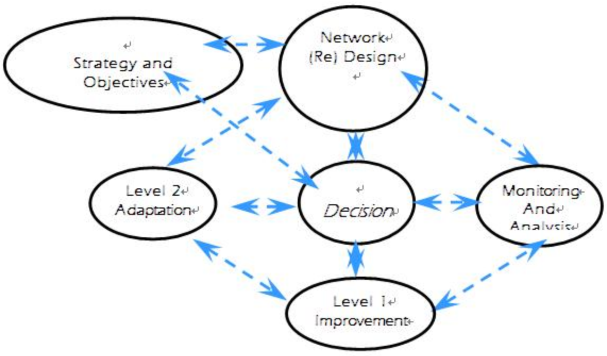

Fig. 6 Revolving decision cycle procedure of levelled interventions for manufacturing networks

V. LAYER EXTENSION OF SOA: RESOURCE AXES FOR PRODUCTION UNITS OR NETWORK SPECIFICATION

For quick descriptions of the resources' situation, the constituent components may be decomposed so the configuration of processes as well as the expression of performance indicators on any level of detail will be supported. In versatile production systems, aspect of wise decompositions have been successfully applied distinguishing between information flows, organisations, and processes as e.g. the specification of the CIM/ OSA framework and consecutive standards. Equivalent resource coordination schemes for networked production have been proposed elsewhere (e.g. 1. physical goods, 2. information, 3. people, and 4. finances).

On self-similarity studies of fractal organisations, specific decompositions have been useful, subdividing into six layers (culture, strategy, socio-informal layer, finance, information, and processes) where the last four layers may be regarded as the resources' scheme (Fig. 7). All layers may carry PN specific methods or KPIs as pointed out in Table II.

With all properties of embedded structures, the layers replicate themselves similarly within all (sub-) units as well as on the corporate or network levels. For better support of the communication, the agreement on IT platforms, on cultural values as well as on standards for interoperability is favourable.

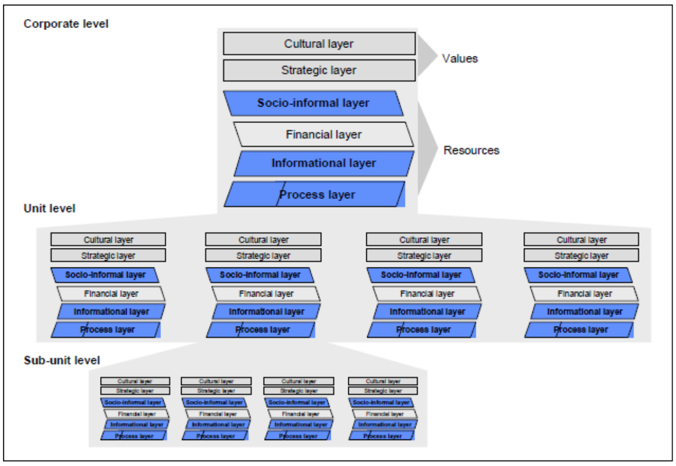

Fig. 7 Self similarity principle applied to enterprise aspect layer decomposition with focus on processes, information, and organisations

TABLE II: examples for layer implementations in pn by industry branches

Resource Layer	*Large automotive supplier*	*Automation equipment SME*	*Pump maker*	
Socio Informal	Teams Team incentives Principles of conduct	Production Circles Decentralised units with quick decision (uneven number), team work Incentive salary prop. PZG = (m*Te + Tr) *100/ At with m: Parts per period Te: time per part Tr: time per set-up At: time of presence	Socio informal elements: . Flat hierarchy Decentralised units with quick decision (uneven number), team work Incentive salary dependant on objective fulfilment Visualisation of objective fulfilment	
Financial	Value stream Design			
Informational		EDP supported JIT linked connections VBS (Electronic Kanban)	Kanban EDP supported Kanban connections to supplier	
Process	O.E.E:	Standard processes/parts:		

In order to support the management of a dispersed manufacturing network, simple patterns of resources' structures may be prescribed for the mandatory internal use. Key elements, most frequently referred to are:

- management principles, as 5s;
- LoD invariant KPIs in LoD invariant dimensions (t, Value);
- methods, as Visual Systems Design (VSD) (Fig. 8).

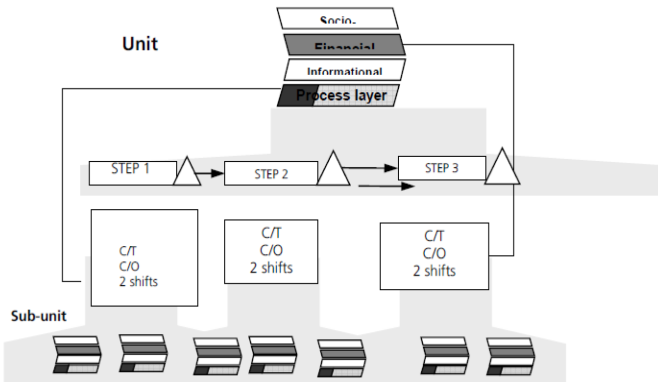

Fig. 8 Layer assignments to Value Stream mapping results as a VSD example

Layer aspects may be filled in to define company-related (self similar) patterns that may also be interpreted as a part of the general definition of a company's specific Production Network "standard". Such standards signalise to the PN units as well as to the partners, e.g. the methods and indicators to be applied. These standards also state clearly what the expectations are and how partners can increase their chances of eligibility and support. Many companies visibly highlight the importance of such network standards by their full commitments, e.g. identification with their company (or brand) names, e.g. Toyota, Bosch, Audi, GKN, etc. Often, all vital elements of these company standards are visualised by self explaining symbols as hierarchical trees or mind maps, being referred to as the companies' "footprints", an instantly appealing practical term for self similarity in the production context. These examples show that managers are well aware that network management requires quite different procedures from what they are using in the hierarchical organisations. The need to permanently restructure and re-link obviously brings about practical solutions that intuitively involve novel principles. The focus of these efforts however is still the streamlining of units' and the activation of process sequences. For efficient configuration of the manufacturing networks, the loop has to be closed from the SoA and the criticality framework to other generic models.

VI. BREAKDOWN OF GENERIC OBJECTIVES

For the continuous update of objectives and resources in a quick and easy manner, predefined (also self similar) patterns that just need to be modified according to the emerging constellations have proven to be a valuable support. In order to detail the objectives on the network level as well as on the unit level, a useful pattern may be defined by a standard list where just the priorities are defined when activated.

The fulfilment of the objectives within any constellation does not necessarily imply that those goals will be identically supported by all assigned lower-level goals. It is rather an intensive communication between the levels and the sub levels ensures the intended self-similarity of these objectives (Fig. 9). With regard to both basic levels' single goal and their combination, consistency can be visualised by an objective pyramid.

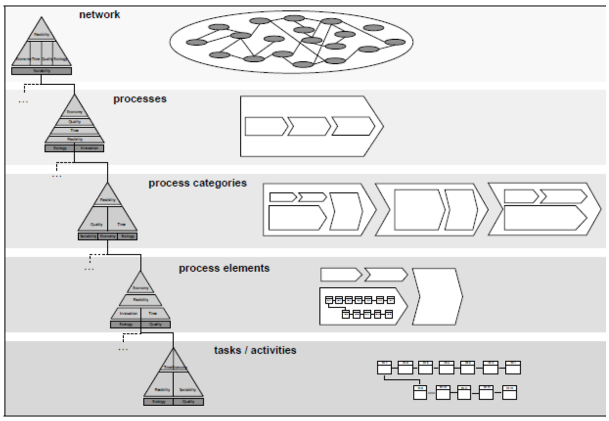

Fig. 9 Self similar generic objective breakdowns in networked organisations

VII. THEORY DESIGN APPROACH

The generic context outlined above can be generalized. The examples explicitly deal with phenomena as unpredictability, self-organization, diversity, and self-similarity as important complexity principles (e.g. [12], [16]). Other findings as the focus on the model world or synergies by adding network units may be seen as specifications of the New Economy Rules that have been intuitively established form observations.

Evidently a PN theory has to build upon fundamental characteristics of complex systems and decision-making in network design and process engineering. The models and procedures outlined implicitly follow five concurrency modes (or principles) for network planning, structuring, operating, linking and improving, comparable to the Object-riented Modelling:

1. the Parallelism mode that exploits the option of achieving shorter execution times by performing multiple stages in parallel or with some overlap; it includes event-driven or real-time updates and evaluations of models;
2. the Emergence mode expressing the proper composition of the overall network and value chain from smaller segments that are concurrently controlled and managed quasi independently;
3. the Behaviour mode defining the dynamics of the synthesized networks and the dependencies on event-driven data and logics as well as interactions of operations;
4. the Iteration mode emphasising the fact that there is an inherent and evolving nature to structuring. Iteration results in changes that must propagate through the structure's stages, requiring continuous process rework;
5. the Encapsulation mode, including all its powerful self-similarity consequences, enabling to build networks and processes by combining elements for creating new entities or for atomising entities to obtain elements respectively as well as to bundle or decompose data networks with the methods that operate on that data.

These five fundamental modes or principles have crucial impact on the models used and their specifications. Models apt to these modes and principles must show substantial generic properties. These generic models are surely of different quality from ordinary application models. Within the set-ups of PN network theory, these models are to be considered as part of the theoretical core and the projections given there.

Production set-ups facing volatility, speed and unpredictability, reach their limits and pressure by new phenomena and call for paradigm change. The examples discussed demonstrate the central role of interlinked models for PN modelling and description. Such contexts may contribute to a theory on the field discussed.

In the conjecture proposed, the PN nodes are not just simple nodes but they also encapsulate rich structures, able to unfold many attributes and properties within the model worlds assigned. Envisioning the network nodes as such, a PN may be seen as a specific Hausdorff space. The topological structure of Hausdorff space allows separating the points, representing the PN nodes, and therefore supporting smooth mappings. This structure appears rich enough to capture the vast majority of configurations occurring in PNs, which is expressed by "attaching" models of attributes, relations and perspectives as tangent spaces to the PN nodes [6]. The PN appears as the Quotient Space of surrounding Kolmogoroff spaces (in topology terms), which may arbitrarily "forget" or "remember" the attached models (Fig. 10).

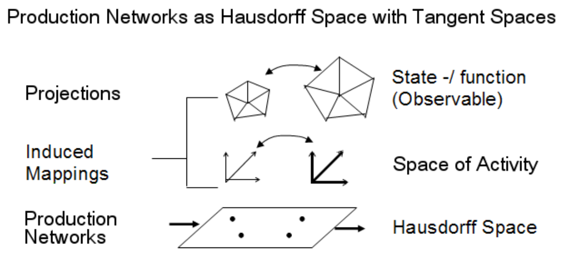

Fig. 10 Production Network as Hausdorff Space with attached space of activity (tangent space) models as used above including derived state/function observable

The entire conjecture may be depicted as an orbital/shell set up (Fig. 11), with

- centred formal theoretical core, (Hausdorff Space);
- a shell of phenomenological laws;
- a model's shell;
- an orbit of real world examples

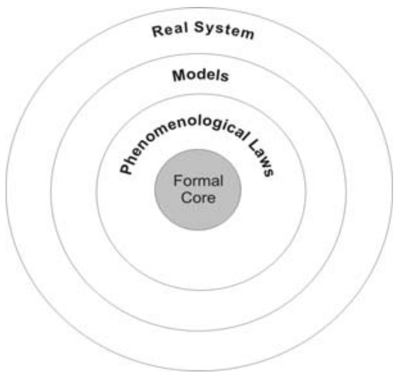

Fig. 11 Production Network Theory set up design: models derived from Real Systems finding a Formal Core Base and follow Principles, Modes and Phenomenological Laws

Since instantaneous and varying models and their relations play a key role in the approach, a prepared pool of PN specific models is the precondition for successful theory application. The first set can be proposed in Fig. 12. This list is open for additional PN models. Some of the models have been used in the examples above.

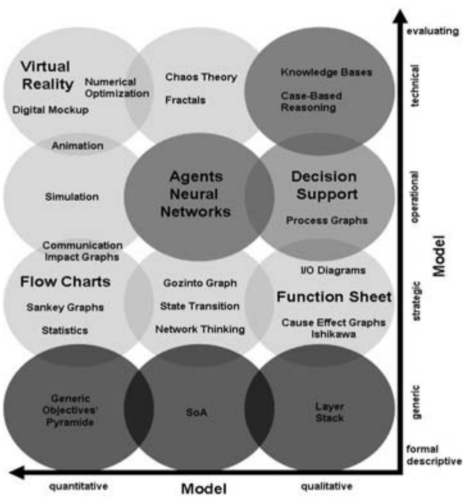

Fig. 12 Portfolio of models frequently used for PN including generic models to be attached to the network units (subset in bold letters is applied for the examples outlined)

As Barbasi [2] advocates, excellent solutions for network problems may be generated by applying/synthesizing rather simple decentralised models that are interlinked. This statement can be endorsed and verified for a specific system of models for PNs and the introduction of simple generic models as well. Resulting interoperability requirements are fulfilled quicker and may marginalize further standardization needs concerning all the models and methods involved. A theory approach, as outlined, helps to pave solid ways into these directions.

VIII. CONCLUSIONS

In the search of competitive excellence in production, PNs have received much attention in the last years. Understanding network characteristics in production gives competitive advantages. However, concepts, typologies, and software supports, etc. have been developed so far mostly as singular, non-coherent problem solutions, where PNs are simply seen as structures, which link production units. This outline could point out that linking the models of PNs and models of units may generate good results. Instead of trying to ignore or even eliminate PN behaviour of network nature, network properties may successfully be used to establish powerful solution procedures. Exploiting network advantages is successful in everyday manufacturing operation planning. Decision procedures in networks should be of gradual and evolving nature. The paradigm behind evidently goes beyond systems thinking and includes complexity, as lots of random interactions may be observed. It induces different decision behaviour, which optimises the networks' structures in total and which smoothly direct networks within ever-changing environments. In order to understand how interdependencies and connectivity evolve over time and what their implications in PNs are, CAS frameworks and MAS applications are frequently pointed at. There have been attempts already to extend the application of complexity theory to the management of supply chains and operations networks. Although these works lay down some initial ideas for the analysis of PNs using the principles of complex adaptive systems, they definitely call for more comprehensive research to further refine and examine the concepts. There are also a number of promising approaches in bioinformatics to be considered for PN specification as well, e.g. [10].

Aiming at obtaining full range coverage of PN problem areas, advantages of network interpretations of production, based on topology and generic models, have been demonstrated. As optimization of processes and not dynamic interlinking of units has been emphasized in modelling in the past, there is a lack of models and methods, apt for dynamic linking (emergent processes) in all layers (personal, informational, process, etc) and on all levels of details. Introducing the concurrency modes and a generic model class may be considered substantial steps towards methods and models for efficient PN management. Further research is needed for the development and integration of improvement techniques as well as coupling, uncoupling, breaking up, and (re)linking instruments. Revolving decision procedures have to be refined, and additional generic models have to be introduced on the way to a stable ever-growing base of knowledge for PNs and PN management.

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